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QUANTITATIVE STRENGTH CHANGES
RESULTING FROM
VARIED ISOMETRIC CONTRACTIONS

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARTS

FACULTY OF PHYSICAL EDUCATION
BY
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EDMONTON, Alberta
April, 1964

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Quantitative Strength Changes Resulting From Varied Isometric Contractions", submitted by Kenneth Ray Williamson in partial fulfilment of the requirements for the Degree of Master of Arts.

ABSTRACT

The purpose of the study was to investigate possible increases in muscular strength, by varying the number of isometric contractions of six seconds' duration at each training session.

One hundred boys enrolled in the required, grade ten, physical education class at Bonnie Doon Composite High School, participated in the study. After initially being measured for muscular strength, the subjects were ranked in order from high to low. The first four were then randomly placed one in each of the four experimental groups, until all one hundred had been assigned. One group became the control group, another the isometric maximal one contraction group, another the ten maximal isometric training group and the fourth the twenty maximal isometric training group.

Each group trained using a six second maximal isometric contraction, with the frequency of the contractions being varied. One group performed one six second maximal contraction, the second group ten six second maximal, the third group twenty six second maximal contractions with the fourth being the control. Each group trained daily, five days per week.

After two and one-half weeks of isometric training all subjects were retested and again at the end of the training session (five weeks). The subjects were tested for strength by using Clarke's Cable-Tension techniques and trained on a modified quadriceps table.

On the basis of the statistical analysis the following conclusions appear to be justified:

1. One daily maximal six second isometric contraction increased significantly the isometric strength of the knee extensors.

2. Ten daily maximal six second isometric contractions increased significantly the isometric strength of the knee extensors.

3. Twenty daily maximal six second isometric contractions increased significantly the isometric strength of the knee extensors.

4. There were no statistically significant differences between any one of the three experimental groups.

ACKNOWLEDGMENT

The writer is grateful for the guidance given to him by his committe members - Dr. M. L. Howell (Chairman), Dr. R. MacNab, Dr. W. A. S. Smith and Mr. H. McLachlin.

The assistance of Mr. A. Bakogeorge, Mr. J. Richardson and Mr. K. Coupe is gratefully appreciated.

A special acknowledgement is extended to his wife, Lorraine, for her typing, assistance and encouragement.

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CHAPTER 1

STATEMENT OF THE PROBLEM

Introduction. In recent years there have been many studies concerned with the effect of isometric contractions on the increase of muscular strength. These studies have produced conflicting results as to the total number of contractions that should be performed to produce positive changes in muscular strength.

In the 1950's, Hettinger and Müller (14) reported on relationships observed between improvement of strength and the frequency and duration of isometric contractions. A brief review of their main findings are: 1. Muscle strength increases an average of five percent per week when the training load is as little as one-third, or even less, of maximal strength. 2. One practice period per day, in which the tension was held for six seconds, resulted in as much increase in strength as longer periods (up to full exhaustion in forty-five seconds). 3. Muscle training increases more rapidly with increasing intensity of training load up to about two-thirds of maximal strength. Beyond this, an increase in training load has no further effect. 4. The rate of increase in strength sometimes varied considerably in the same person when two comparable training periods separated by a long rest period were compared. 5. Several maximum contractions, one after the other, (as many as twelve contractions in a one-second rhythm) did not increase the strength any faster than only one contraction .

In 1959, Müller (26) hypothesised that permanent increase in muscular strength might be obtained by training over long intervals, whereas, if the training intervals were short, the attained strength could be retained only by maintenance of training, though the frequency of contractions may be reduced.

Petersen (29), in his study, presented conflicting results. He concluded that one daily maximal isometric contraction had no effect on the isometric strength of the muscles, and ten daily maximal isometric contractions had a tendency to increase the isometric strength of the muscles.

Hettinger and Müller, in their studies, allowed the subjects to train on the same dynamometer every day that the tests were performed on. Petersen concluded (29) that this procedure could possibly modify the final results, as improvement could actually be due to the learning factor (how to use the dynamometer) rather than true strength increases. In the present experiment the subjects will train with one device and will be tested for muscular strength with another apparatus.

Asa (2), also reported results contradictory to the findings of Hettinger and Müller. He reported that repetitive isometric exercises (twenty contractions daily for six seconds) produced an increase of muscle strength which was significantly higher than that which resulted from a single isometric program (one contraction daily for six seconds).

In 1963, Müller (27) reinvestigated his findings and revised

some of his original conclusions such as: 1. During training, if there were an increase in the intensity of the contraction from two-thirds maximal to maximal, the speed of increase of final strength could almost be doubled. 2. If the number of daily contractions could be increased from five to ten, a higher final strength could be obtained.

The Problem. The purpose of this study is to investigate possible increases in muscular strength, by varying the number of isometric maximal contractions of six seconds' duration at each training session. More specifically, the study will compare the effects of three training programs, consisting of one six second maximal isometric contraction, ten six second maximal isometric contractions and twenty six second maximal isometric contractions on the development of isometric muscular strength of the extensors of the preferred leg.

Null Hypothesis. In the present study, the null hypothesis asserts that there is no significant differences as a result of the different training periods between any of the groups, compared to the control.

$$Ho = \mu_1 = \mu_2 = \mu_3 = \mu_4$$

The alternative hypothesis suggests that there is a significant difference between the groups as a result of the different training methods.

Limitations of the Study.

1. The subjects in this study will be one hundred boys, enrolled in a required, grade ten, physical education class in Bonnie Doon Composite High School, in the city of Edmonton.

2. The study consists of one week pre-testing, five weeks of the exercise program, and one week of post-testing.

3. The muscles involved are the extensors of the preferred leg.

4. The form of exercise will consist of six second maximal isometric contractions, one group performing one contraction, another group ten contractions and the last group twenty contractions, five days a week for six weeks.

5. All experimental subjects will participate in the regular physical education activity volleyball, along with the control group, except for the experimental period.

6. The ages of the subjects will fluctuate between sixteen and eighteen years.

7. The subjects will train on a modified quadriceps exercise table, and will be tested by using the cable-tension technique.

8. A three second rest will be allowed between contractions.

Definitions. In this study, the following definitions apply:

Strength. Strength is the capacity of a muscle to exert force against a resistance and is measurable only by a single maximal effort.

Isometric Contraction (static contraction). An isometric contraction occurs when the muscle develops sufficient tension which is insufficient to move a body part against resistance. The muscle length does not change.

Maximal. Maximal refers to the maximal voluntary effort that a subject is able to perform while contracting muscle.

Single Isometric Contraction. A single isometric contraction is an exercise in which the muscle contracts once maximally for a six second period.

CHAPTER 11

REVIEW OF THE LITERATURE

Use of isometric contractions in training began following the publication of the experiments of Müller and Hettinger (14). Over an eighteen month period, nine male subjects participated in seventy-one experiments, in which training took the form of pulling and holding a pre-determined amount of tension against a spring scale by contracting the flexors and extensors of the forearm. Steinhaus (37:4) has reported and summarized the main initial findings of Hettinger and Müller on isometric exercise. Findings pertinent to this study are (37:6):

1. Muscle strength increases an average of five percent per week when the training load is as little as one-third, or even less, of maximal strength.
2. Muscle strength increases more rapidly up to about two-thirds of maximal strength. Beyond this, an increase in training load has no further effect.
3. One practice period per day in which the tension was held for six seconds resulted in as much increase in strength as longer periods (up to full exhaustion in 45 seconds), and more frequent practices (up to seven per day).
4. The rate of increase in strength sometimes varied considerably in the same person when two comparable training periods separated by a long rest period were compared.
5. There is a ceiling on the development of strength in every muscle. Attainment of this maximum is usually accompanied by pain resulting from some injury within the muscle that stops further increase in effort.

Hettinger (13), in a recent publication, has revised some of these earlier conclusions. He states that the maximal observable training effect is about three to four percent per week

rather than the original five percent. He also states:

1. It was interesting to find that the maximum training effect possible was achieved by using only forty to fifty percent of the maximum strength in voluntary isometric muscle contraction (13:25).

2. The intensity of the training stimulus must be increased every fourteen days as the maximum muscle strength itself increases during this time between the two measurements (13:26).

3. Maintaining a maximum isometric contraction for only one or two seconds is sufficient to provide a training stimulus. When the contraction involves only two-thirds of the maximum strength it should be maintained approximately four to six seconds (13:28).

4. It was found that the maximum increase in muscle strength was obtained with one training stimulus per day (13:29).

5. Also, several maximum contractions, one after the other, did not increase strength any faster than only one contraction (13:30).

In 1963, Müller and Rohmert (27) re-investigated and revised some of the original conclusions, such as:

1. During training, if there were an increase in the intensity of the contraction from two-thirds maximal to maximal the rate of increase of final strength could almost be doubled.

2. If the number of daily contractions could be increased from five to ten, a higher final strength could be obtained.

Although the findings of Hettinger and Müller have not been exactly duplicated, many statistically significant findings have resulted from experimentation with isometric training programs.

Strength Development. Taylor (39) studied the effectiveness

of four isometric training programs in developing strength in dorsal flexion of the right wrist, and lateral rotation of the right thigh. Using both muscle groups, Group 1 held a maximum pull for twelve seconds; Group 11 held a maximum pull for six seconds; Group 111 held a two-thirds maximal pull for twelve seconds and Group 1V held a two-third maximal pull for six seconds. Not one of the four static contraction methods used was significantly better than each of the others for the purposes of producing strength except that the two-thirds maximal pull for six seconds was significantly better than the two-thirds maximal pull for twelve seconds in lateral thigh rotation. All training methods, other than the two-thirds maximal for twelve seconds, produced a statistically significant improvement in the contractile strength of muscles involved in movement of the right wrist dorsal flexion as compared to the contractile strength of the same muscles of a none-trained control group. The maximum pull for twelve seconds and the two-thirds maximal for six seconds produced a significant improvement in right hand outward rotation strength as compared to the control group. The author suggested that the mean of the experimental group was always higher than that of the control group, although this increase was not always statistically significant.

Lorback (22) reported statistically significant increases in strength by a single contraction held for six seconds at two-thirds maximal three times a week. There were eight weeks of training.

Howell and Shaw (16) reported statistically significant increases in the grip strength of nineteen boys who practiced one daily six second maximal contraction of the right wrist flexors, for four weeks.

Gardner (8), using four groups, trained three groups at varying angles, with one group used as a control. Groups 11, 111, and 1V, exercised three times per week for six weeks, on Mondays, Wednesdays, and Fridays using a single six second isometric contraction against two-thirds of the maximum tension loads. The results showed that all the exercise groups made significant improvement in total strength at the .01 level of confidence. No group improved significantly at any angle other than the one at which it trained.

Perkins and Kaiser (28), studying the effects of a single six second maximal isometric exercise on three muscle groups three times weekly with older people (twenty subjects, age range sixty-two to eighty-four, with a mean age of seventy-three point six), found that the subjects showed a gain of approximately fifty percent in strength at the time of plateau.

Wolbers and Sills (43) found that six second maximal isometric contractions, performed daily by twenty grade eleven high school boys, resulted in strength increases. The experimental group gains were statistically significant in back lift, leg lift and combined hand grip, at the one percent level of confidence. It was concluded that isometric contractions of six seconds' duration

will cause significant gains in strength.

Rarick and Larsen (30) studied three groups of post-pubescent males, equated on the basis of initial strength test scores of the wrist flexor muscles as measured by a cable tensiometer. Group 1 followed the Hettinger and Müller procedure, holding a two-thirds maximal contraction for six seconds daily, Monday through Thursday; Group 11 held eighty percent maximal tension for five periods of six seconds on Monday, increasing the number of exercise bouts until reaching a maximum of eight on Thursday. Both experimental groups made gains that were significantly higher than the control. The data indicated that a once-daily two-thirds maximal tension exercise bout was as effective as tension levels above two-thirds maximum and more frequent exercise bouts. These findings generally supported the Hettinger-Müller hypothesis of static strength development.

Walters, et al.(40) investigated the effects of two isometric training programs. The two programs studied were isometric training with maximal resistance and with two-thirds maximal resistance. They found that both methods were effective in increasing strength significantly.

In contradiction to the above mentioned findings regarding the effectiveness of single isometric contractions for strength gains, other researchers have presented conflicting evidence that does not support the development of strength as a result of a single isometric contraction.

Petersen (29) compared the effect of muscle training by static, eccentric and concentric contractions. Isometric strength of the right elbow flexors and the right knee extensors was measured by a Darcus strain gauge, with the subjects training on a Collins dynamometer. Seventeen young female and seventeen young male subjects under went a training period of from twenty to thirty-six days. The training program consisted of one daily maximum isometric contraction (five seconds); ten daily maximum isometric contractions and ten daily eccentric muscular contractions of fifteen minutes riding a bicycle ergometer. The isometric contractions consisted of five second maximal contractions with repeated contractions made every thirty seconds. The effect of the isometric strength of the trained muscle groups was measured and compared with that of a control group of seven females and six males, which received no training. It was found that one daily maximum isometric contraction had no effect on the isometric strength of the muscles, and ten daily maximum isometric contractions had a tendency to increase the isometric strength of the muscles. Petersen (29:416) stated that the best kind of training program to provide the most favourable increase in strength cannot be given, but the results suggested that an increasing number of contractions would lead to increasing muscle strength.

Hislop (15) used ninety-one subjects in fourteen different exercise groups. Eight of these performed maximally at each bout,

four performed at seventy-five percent of their calculated maximal strength and two groups exercised at sixty-seven percent of their peak strength. There were four different exercise frequency periods: two bouts daily, one bout daily, three bouts weekly and two bouts weekly. The duration of isometric holding was at six and fifteen seconds for each frequency. The experimental period lasted forty-two days for each subject. All measurements of isometric tension of the left forearm flexor muscles were made with an adjustable electronic dynamometer. All exercises were carried out on an exercise table with adjustable footboard and shoulder supports. Each subject learned how to exert a maximum isometric contraction against the dynamometer in the exercise position. The five percent per week improvement in maximal strength reported by Hettinger and Müller was not achieved by any group in this study. The greatest mean improvement, approximately 3.5 percent, occurred in a group which exercised at the greatest frequency (two bouts daily) for durations of fifteen seconds at each bout. The mean improvement after six weeks in the group that exercised for six seconds daily at two-thirds of their maximal strength was less than one percent per week. The gains elicited by maximal exercise in this investigation, however, invariably exceeded gains elicited by submaximal exercise. The study indicated that increasing the exercise frequency beyond one contraction daily elicited greater gains in maximal strength than did increasing the duration of isometric holding from six seconds

to fifteen seconds.

Howell and Shaw (17) reported statistically significant increases in measures of strength (back lift, leg lift) when the subjects (twenty university students) performed eight daily contractions against an immovable bar in eight different positions. Each contraction was held maximally for six seconds.

Liberson and Asa (21) reported increases of one hundred and thirty to one hundred and seventy four percent in maximal strength of the hypothenar muscles after nine weeks of single six second contractions. The abductor digiti quinti muscle, which is mostly used in physical activities, can be said to have a greater potentiality for development because of its lack of use. The two programs studied were a single contraction and a twenty-times daily contraction, both held for six seconds. These workers found that by increasing the frequency of isometric bouts of exercise greater gains were produced in strength than exercise once daily.

Adamson (1) showed a significant increase in strength following four weeks of isometric training (six maximal contractions at ten second intervals on each of two dynamometers). The subjects were young boys (mean age eleven point five years) from Leeds Grammar School.

Asa (2) reported that twenty contractions daily, held for six seconds, performed four days a week for twelve weeks, produced a significantly higher degree of strength than a single isometric

group (one contraction a day for six seconds, four days a week for twelve weeks). However, he reported that each subject in both groups showed significant increases in strength.

Mathews and Kruse (23) compared the results of three consecutive, six second maximal contractions using Clarke's Cable-Tension Strength Tests, with isotonic exercises to exhaustion on the Kelso-Hellebrandt Ergometer with a weight load equal to 3/16 maximum strength. Sixty subjects exercised isometrically and sixty isotonically. Each group was divided into four, and exercised two, three, four and five times a week. Because no common regression line existed in any group with regard to strength changes, it was concluded that the strength gain is dependent upon the individual rather than upon the type of exercise he practices, or the frequency with which he exercises. In both groups, as exercise frequency increased, a greater number of subjects gained significantly in strength. Forty-one of the sixty in the isotonic group increased their strength scores, while forty-four of the sixty in the isometric group made statistically significant gains in strength.

Rasch and Morehouse (32) tested the effectiveness of three isometric flexion curls, for fifteen seconds each with three minutes rest, at two-thirds maximum strength. After training three days a week for six weeks, it was found that the subjects had not increased significantly in strength.

However, following isometric arm elevator exercises with conditions the same as above, the isometric group showed a statistically significant increase in strength.

Meadows (25) found a strength improvement, statistically significant at the one percent level, in vertical jump, left leg lift, and back lift, following isometric training three days a week for ten weeks.

Steinhaus (38) suggested that a six second contraction of the abdominal muscles held six times daily would strengthen weak muscles of the abdominal wall.

Rasch (31) reported that a program of repetitive squeezing of a rubber ball three days a week over a six week period resulted in a significant increase in grip strength.

Darcus and Salter (5) studied the effect of daily training sessions which consisted of thirty isometric contractions at intervals of one minute. This training program of thirty contractions per day for twenty-five days produced an increase in isometric strength of eighteen to forty-six percent. They concluded that a training program utilizing one to ten maximum isometric contractions per day was ineffective for strength gains.

Salter (35) found, in a similar experiment to the above, increases of fifty-two to eighty-eight percent in isometric strength as a result of training by thirty maximum isometric contractions. If these observations are correct, then it is

possible that thirty maximum isometric contractions per day are apt to increase isometric strength, while one or even ten maximum contractions per day are inadequate to induce changes.

Hansen (9) reported an increase of eleven percent in isometric strength. The number of daily contractions was nine for a period of thirty training days.

Hansen (10) reported, from an earlier study, where the subjects performed one hundred and fifty contractions daily, for thirty days during five weeks, that the isometric strength was unchanged but that the capacity to perform the specific isometric task increased significantly. The subjects stood with the left elbow in ninety degree flexion. By means of a handle and a wire, a load of sixty percent of the IRM was lifted a few millimeters from the support, and in this way the contraction was performed without any considerable shortening. The contraction was maintained for five seconds with a two-second rest.

Mayberry (24) studied the effects of maximal and submaximal (fifty percent) isometric contractions performed once daily for five weeks. The analysis indicated that in no instance was there a statistically significant increase in the average strength scores of the exercised wrist flexors. Mayberry's study indicated that a single isometric contraction done once a day was not a sufficient amount of exercise to

result in an increase in strength.

Wickstrom (42) and Hayman and Schneider (11) also observed no strength increases following isometric training.

Hansen (10:476) stated that in all the literature concerned with training of human muscles, divergences in results were a striking feature, especially the effect of training on the isometric strength, in almost identical experiments. Hettinger and Müller (14) are exponents of the view that very few isometric contractions give an excellent training response. Petersen (29) and Rasch and Morehouse (32) represent the opposite point of view.

CHAPTER 111

METHODS AND PROCEDURE

The subjects were one hundred grade ten boys enrolled in the required physical education program at Bonnie Doon Composite High School, located in Edmonton. All the subjects participated in the required physical education program which was volleyball, and were not actively engaged in any other physical activity. Testing and training procedures were carried out from nine a.m. to eleven a.m. on each school day. The average age of the subjects was sixteen point four years, with a standard deviation of eight point three months. Height and weight were also recorded. No testing or training was carried out on Saturdays or Sundays.

The pre-testing period covered a period of three days plus an additional two days for repeating the measurements on thirty subjects, randomly selected from the class. In order to establish the test re-test reliability of the measurements, the Pearson product-moment correlation was used. The training program was carried out during the following five weeks.

The cable-tension technique described by Clarke (4) was used to measure the strength of the preferred leg.

At the end of the pre-test period the subjects were equated on the basis of the initial strength measured and placed into four groups. Each group trained using a maximal six second isometric contraction, with the frequency of the contractions being varied. One group performed one six

second maximal contraction, the second group ten six second maximal contractions, the third group twenty six second maximal contractions with the fourth being the control group. The experimental subjects took part in the regular physical education classes, except when they performed their isometric exercises.

Apparatus: The testing procedures were carried out on the Clarke Testing Table, which is approximately six feet six inches long, two feet nine inches wide, and two feet six inches high, with a padded top.

The isometric exercises were carried out on a modified quadriceps exercise table.

Testing Equipment: 1. Tensiometer: The aircraft tensiometer was the instrument used in recording muscle strength. Cable tension is determined by measuring the force required to create offset (on the riser) in the cable between two set points (the sectors). This tension then is converted directly into pounds on a calibration chart. A tensiometer capable of testing four hundred pounds was used.

2. Pulling Assembly: (a) Chain and Snap: The chain and snap are made of a short piece (twelve to eighteen inches) of one-sixteenth inch extra flexible cable attached to a light welded link chain about three feet long.

(b) Regulation Strap: The regulation strap is constructed from a double thickness of parachute webbing (two feet six

FIGURE I Equipment For Measurement of
Isometric Strength:
Regulation Strap, Chain and Snap
Goniometer
Tensiometer

FIGURE II Measurement of Isometric Strength
(Clarke's Cable-Tension Technique)

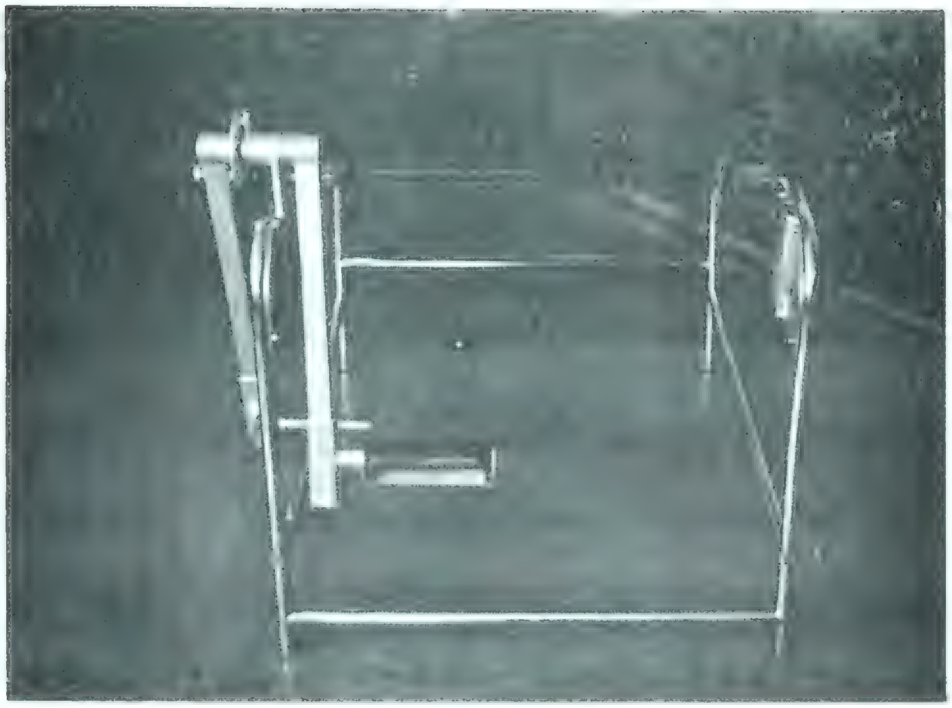

FIGURE III Modified Quadriceps Table
(Training Apparatus)

FIGURE IV Subject Performing Maximal Isometric Contraction

[illegible]

[illegible]

inches long and two inches wide), stitched firmly around a D-ring. A keeper is attached around the strap making it adjustable.

3. Goniometer: The goniometer was used for measuring the knee angle. This instrument consists of a one hundred and eighty degree protractor made from steel with two arms fifteen inches long. One of these arms is stationary, extending along the zero line; the other is movable, permitting rotation to the proper angle.

Measurement of Strength: The subject was seated in a backward leaning position, arms extended to the rear, with the hands grasping the side of the table. The back of the subject's preferred knee was placed against the end of the testing table. The knee on the side to be tested was placed at one hundred and fifteen degrees extension. The regulation strap was placed around the leg midway between the knee and ankle joints. The pulling assembly was then attached to a hook at the lower end of the table. The subject was instructed to pull on the cable and to make as strong an effort as he could within his individual tolerance. Each subject had three trials, measured at intervals of two minutes. The individual's score consisted of the average of three trials (41). Each subject was prevented, by use of an assistant, from lifting his buttocks and flexing the arms.

Description of Exercises:

Starting position 1. The subject sat with his hands

gripping the outer edges of the exercise table, with the elbows in the extended position. An automobile safety belt was pulled tightly across the thighs, preventing the hips from lifting.

2. The lower portion of the preferred leg hung loosely from the knee over the end of the exercise table and the ankle was hooked behind the ankle bar which was at one hundred and fifteen degrees to the table top.

3. At a given signal the subject made a maximal isometric contraction against the fixed bar for six seconds. The seconds were counted out by the experimenter. At the end of the six second contraction the subject relaxed his leg returning it to the resting position.

4. In Group 1 each subject performed one six second maximal contraction. The subjects in Group 11 performed ten six second maximal contractions with a rest period of three seconds between each contraction. Group 111 performed twenty six second maximal contractions with a rest period of three seconds between each contraction.

5. A strength test was given after a period of two and a half weeks (mid-test), using Clarke's Cable-Tension techniques. The individuals mid-test strength score consisted of the average of three trials (41).

6. The final strength test was given after five weeks, Clarke's Cable-Tension techniques were also used during the final trial, with the average of three trials recorded as the subject's final strength score.

CHAPTER 1V

RESULTS AND DISCUSSION

Results

The mean heights and weights and standard deviations of the four groups used in the study may be seen in Table 1.

TABLE 1

MEANS AND STANDARD DEVIATIONS OF HEIGHT AND WEIGHT OF SUBJECTS IN EACH GROUP

Variable	Statistic	Group 1	Group 2	Group 3	Group 4
Height (inches)	Mean	67.3	67.3	68.2	66.8
	S.D.	±9.49	±7.97	±8.38	±7.91
Weight (Pounds)	Mean	142.4	133.6	141.5	130.3
	S.D.	±23.46	±15.04	±17.25	±13.02

The Pearson Product-Moment method was used to determine the test-re-test reliability of the measurements used.

TABLE 11

TEST-RE-TEST RELIABILITY COEFFICIENT

Variable	Number of Subjects	Reliability Coefficient
Strength	30	0.86

The determined reliability coefficient of 0.86 was found to be statistically significant beyond the .01 level of confidence (for thirty subjects ($r \geqslant 0.449$).

Figure 1 illustrates graphically the strength differences in the four groups at the three testing periods. Tables 111 and 1V further explain these changes.

TABLE 111

PERCENTAGE INCREASES OF STRENGTH FROM THE INITIAL TEST TO THE MID TEST TO THE FINAL TEST

Increases	Group 1	Group 2	Group 3	Group 4
Percent Increase Initial To Mid-Test	17.8	16.8	20.1	4.3
Percent Increase Mid-Test To Final Test	10.0	12.7	14.9	.85
Percent Increase Initial To Final Test	29.7	31.8	38.0	5.2

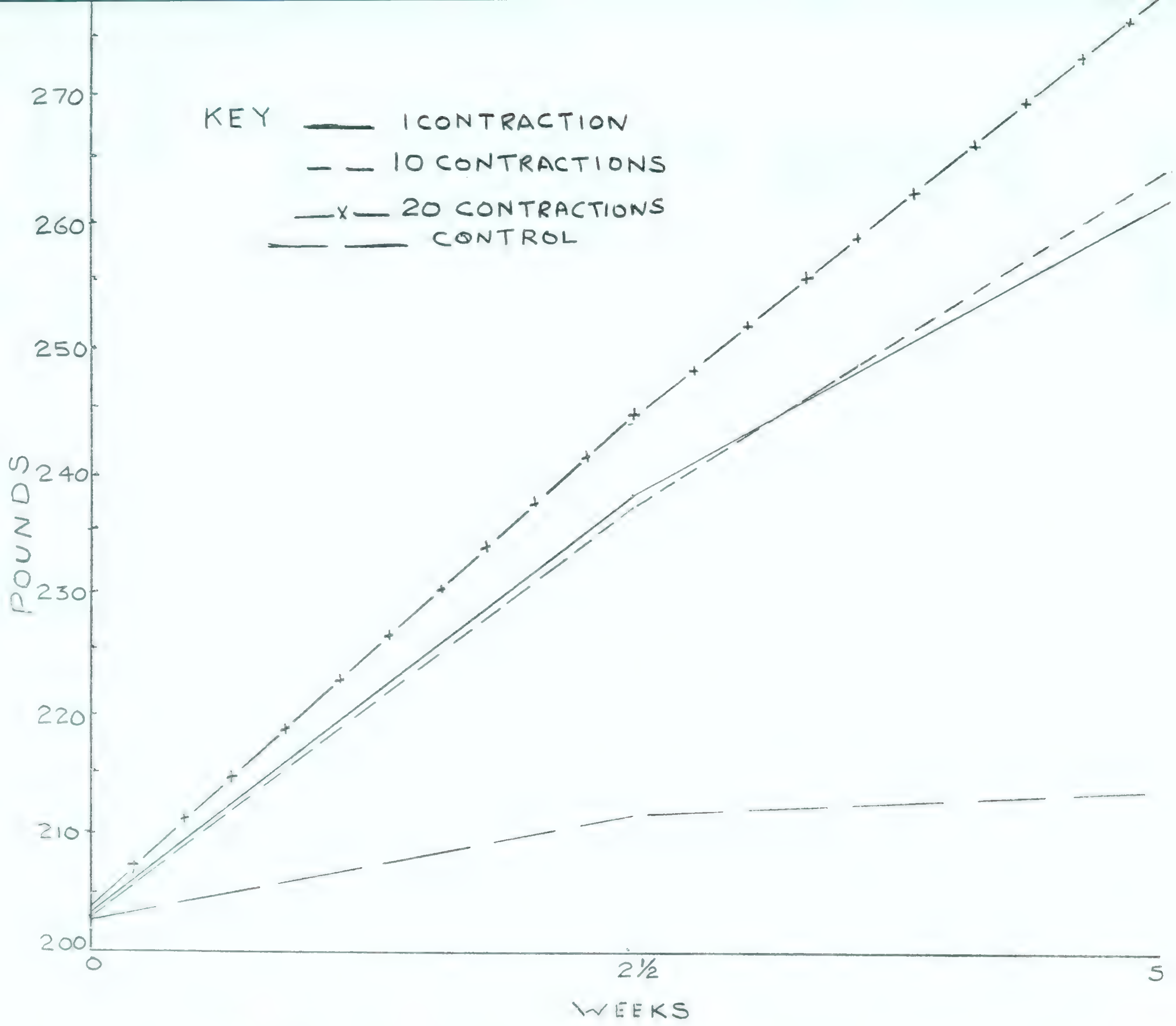

FIGURE V STRENGTH DIFFERENCES IN THE FOUR GROUPS AT THE THREE TESTING PERIODS

TABLE 1V

MEAN CHANGES IN STRENGTH AT THE THREE TESTING PERIODS (INITIAL, MID, AND FINAL TEST)

GROUPS	INITIAL (POUNDS)	MID (POUNDS)	FINAL (POUNDS)
Group 1	203.00	239.24	263.28
Group 2	202,88	237,28	267,48
Group 3	203.6	244.56	281.04
Group 4	202.16	211.88	213.68

Following the first half of the training program (two and one-half weeks), a mid strength test was recorded, and after the five weeks of training a final strength test was completed. The means of Group 1 increased from 203.0 pounds to 239.24 pounds, a percentage increase of 17.8 percent, on the mid-test means. The means of the initial test increased from 203.0 pounds to 263.28 pounds on the final test, a total increase of 29.7 percent.

The means of Group 2 increased from 202,88 pounds to 237.28 pounds on the mid-test (16.8 percent increase), and from 202,88 to 267.48 pounds (31.8 percent increase) on the final test.

It was found that the mean strength had increased from 203.6 pounds to 244.56 pounds on the mid-test (14.9 percent), and from 203.6 pounds to 281.04 pounds (38.0 percent) on the final test in Group 3.

The control group was found to have a slight increase in mean strength from 202.16 pounds to 211.88 (4.3 percent) on the

mid test, and an increase from 202.16 pounds to 213.68 pounds on the final test (5.2 percent).

TABLE V

ANALYSIS OF VARIANCE FOR STRENGTH

Source of Variation	Sums of Squares	df	Mean Square	F
Groups	49,518	3	16,506.00	11.53*
Trials	143,763	2	71,881.50	115.22*
Blocks	398,251	24	16,593.79	
Blocks X Groups	103,032	72	1,431.00	
Groups X Trials	31,482	6	5,247.00	8.43*
Blocks X Trials	29,913	48	623.86	
Blocks X Trials X Groups	89,678	144	622.76	
Total	845,637	299		

* Statistically significant at the .01 level of confidence.

TABLE VI

DUNCAN'S TEST FOR MULTIPLE COMPARISON IN THE ANALYSIS OF VARIANCE

Source of Variation	Sums of Squares	df	Mean Square	F
Between Groups	65,055	3	21,685.3	
Within Groups	232,245	96	2,419.21	
Total	297,300	99		

TABLE VII

DUNCAN'S NEW MULTIPLE RANGE TEST APPLIED TO THE DIFFERENCES BETWEEN K = 4 TREATMENT MEANS

Means	213.7	263.3	267.5	281.0	Shortest Significant R
213.7		49.6	54.2	67.3	R= 37.0
263.3			4.2	17.7	R= 38.5
267.5				13.5	R= 39.6

There was a statistically significant difference between the three trial means, which have been averaged over the four groups (Table lV). The resulting F was 115.22, which was statistically significant at the .01 level of confidence.

In the groups the means have been averaged over the three trials, more closely corresponding to the general overall measure of performance for each group. The resulting F of 11.53 was statistically significant at the .01 level, indicating that there was a significant difference between the four means.

The interaction, or groups by trials, also had a statistically significant value for F of 8.43 the .01 level of confidence. The significant value indicates that the strength curves for the groups were not of the same form, that is slope. If the strength curves were exactly parallel, the interaction sum of squares would be zero.

As there were statistically significant values for the

strength increases in the three groups, further analysis was undertaken to see if any significant differences were present between the three training groups. The Duncan Multiple Range Test indicated that each of the experimental groups gained significantly at the .01 level of confidence over the control group, but that there were no statistically significant differences between any one of the experimental groups.

Discussion

The group performing one isometric maximal contraction daily, five times per week, made statistically significant increases over the control group. The groups which performed ten and twenty isometric maximal contractions daily, five times per week, likewise demonstrated statistically significant increases over the control group.

Hettinger and Müller (14), in their original studies, stated that one practice period per day, in which the tension was held for six seconds, resulted in as much increase in strength as longer periods up to full exhaustion in forty-five seconds and as many as seven contractions a day. The present study, therefore, supports their original findings, but the experimental procedures in the two studies were different.

Müller (27), in a later publication, stated that; 1. During training, if there were an increase in the intensity of the contraction from two-thirds maximal, the speed of

increase of final strength could almost be doubled and, 2. If the number of daily contractions could be increased from five to ten, a higher final strength could be obtained.

In the present study the contractions were maximal, so conclusions were not made with respect to increasing the tension from two-thirds maximal to maximal. With regard to increases in the number of daily contractions from five to ten, the mean findings parallel those of Müller, that is, that a higher final strength could be attained, but in this study these differences were not found to be statistically significant. Likewise, there was a further mean increase resulting from ten to twenty isometric maximal contractions daily, but again no statistically significant increases were demonstrated between the groups.

The findings with respect to statistically significant increases in strength following one daily contraction are supported by the studies of Taylor (39), Lorback (22), Howell and Shaw (16), Perkins and Kaiser (28), Wolbers and Sills (43), and Rarick and Larsen (30). These positive findings regarding the effectiveness of a single isometric contraction for strength gains, did not occur in the studies of Hislop (15), Howell and Shaw (17), Liberson and Asa (21), Mathews and Kruse (23), Rasch and Morehouse (33), Rasch (31), Darcus and Salter (5), and Hansen (10).

Petersen (29) compared muscle training by static, concentric and eccentric contractions. He used the right

knee extensors and the right elbow flexor muscles. The isometric strength was measured with a Darcus dynamometer, but the subjects trained on a Collins dynamometer, rigged as a tensiometer. Seventeen young male and seventeen young female subjects underwent a twenty to thirty-six day training period, which consisted of a performance of one daily isometric contraction (five seconds), ten daily maximum isometric contractions and fifteen minutes riding a bicycle ergometer. Seven females and six males acted as controls.

Petersen stated that (29):

1. A daily maximum isometric contraction had no effect on the isometric strength of the muscles.
2. Ten daily isometric contractions had a tendency to increase the isometric strength of the muscles, but not significantly.
3. Ten daily maximum eccentric contractions had no measurable effect on isometric muscle strength.

Furthermore, he concluded that the best kind of training program to provide the most favourable increase in strength cannot be given, but the results suggested that an increasing number of contractions would lead to increasing muscle strength.

Petersen also reported (29:415):

> An important point which must be considered in evaluating the present as well as other results, relates to the instrumentation utilized to measure the increase in strength and endurance. If the same instrument is used for training and testing, it is possible that improvement in skill would occur. This induces a factor which cannot be evaluated, nor is it clear if different test methods are subjected to this influence of skill in the same degree. The results of Hettinger and Müller (1953) and Darcus and Salter (1955)

> are both dependent upon an experiment where the same instruments are used for training and testing. The effect of isometric training in these two works may, therefore, be attributed to improvement in skill.

These comments and the results of Petersen have caused considerable debate by investigators in the field of strength training. The points raised were logical and it appeared as if the majority of the research done in this area might have been invalidated. The present study is the first to investigate the findings of Petersen and to parallel his study.

In the present study, the potential learning factor or what Petersen refers to as improvement in skill, was controlled by testing the subjects using Clarke's cable-tension techniques and by training on a modified quadriceps table. Two different pieces of apparatus, then, were used for training and testing.

However, the present findings are contradictory to those of Petersen, though the controls appear to be at least as rigid. In fact, each of the three main conclusions of Petersen are negated. Statistically significant increases in strength were found with one daily maximum isometric contraction, with ten daily maximal isometric contractions and with twenty daily maximal isometric contractions. Although the means increased depending on the number of daily contractions, the differences between the groups were not statistically significant. Each of the differences compared to the control group was statistically significant at the one percent

level of confidence, whereas Petersen did not find significant increases using the two percent level of confidence as the acceptable level of significance. It should also be mentioned that both studies used the same muscle groups, though Petersen did use the elbow flexors as well.

The divergence of the two parallel studies is difficult to explain. One explanation might have been motivation. In the present experiment attempts were made to equally motivate each training group. When recording strength the "shouting" technique, suggested by Ikai and Steinhaus (18), was followed. Petersen did not refer to this aspect in his study and his results might be attributed to this.

Jones (20) attempted to determine the reliability of a standardized active strength test and secondly to assess the effects of subtle motivation of a type commonly used in the clinic. Subjects were placed into three groups, similarly tested but subjected to one of three different conditions of motivation. Conditions were duplicated two days later on a re-test. The isometric strength of the major muscle groups of the thigh and the quadriceps was measured with a recording tensiometer. It was concluded that isometric strength testing so administered is a reliable procedure.

Hellebrandt and Waterland (12), on the other hand, found that observation of others alone had a measurable influence in ergometer performance.

Darcus and Salter (5) observed that dynamic training produced a greater percentage of improvement, possibly because the subjects were better motivated. The subjects, they noted, became bored with static training.

Rasch and Morehouse (32), stated their subjects expressed a dislike for isometric effort. They complained it was frustrating to exert their full strength and "see almost nothing happen" and that this type of exercise was boring. In view of their negative attitude, there may be some question as to whether subjects would voluntarily work as hard under isometric conditions as under isotonic.

The findings in the present study did not substantiate the boredom noted by Darcus and Salter (5) and Morehous and Rasch (31). This could, of course, occasion considerable changes in performance. The age group in this study, high school boys, could perhaps account for the difference of opinion, as no problem was observable with respect to motivation.

The findings of Ikai and Steinhaus (18), are evidence that (18:13)

> "... maximum physiological strength is greater than our measurements of voluntary isometric contractions would indicate."

Other possible causes of the discrepancy between the present results and those of Petersen have to do with age and sex. Sex, for example, is one factor which may limit and affect strength (6,13,20). Trainability is less in women

than in men (13). Petersen, for example, used women subjects in his study and this could have affected the group increases, as well as his general conclusions.

Petersen has used the following three factors which would limit the possibility of significant increases in strength in his study: a small number of subjects (approximately ten in each group), groups composed of fity percent females (who are not as trainable as men in strength) and a high level of acceptable significance (the null hypothesis was rejected at the 0.02 level).

Further examination of Petersen's data revealed the validity of some of these objections and some of the basic reasons for the discrepancy of the data in the two studies (see Table V11l and 1X).

TABLE V111

AVERAGE ISOMETRIC TORQUE (MAXIMUM OF FIVE TRIALS) IN KG x CM OF THE TRAINED RIGHT ELBOW FLEXORS COMPARED TO THE CONTROLS[1]

Sex and Side	Time of Test	Group 1 5 females 5 males 1 isom. contr/day	Group 11 4 females 6 males 10 isom. contr/day	Controls 7 females 6 males no training
Females				
	before training.	500±70	460±20	469±26
	after 9 days	452±51	438±37	430±29
	after 18 days	462±63	448±28	431±31
	after 27 days	452±35	438±13	416±38
	after 36 days	460±36	465±17	433±39
Males				
	before training.	790±48	829±33	820±45
	after 9 days	810±110	897±35	835±47
	after 18 days	818±56	860±43	782±37
	after 27 days	826±68	880±57	822±49
	after 36 days	837±78	962±49	839±56

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[1] From Petersen, "Muscle Training by Static, Concentric and Eccentric Contractions", *Acta Physiol. scand.*, vol. 48 (1960), p. 410.

TABLE 1X

AVERAGE ISOMETRIC TORQUE (MAXIMUM OF FIVE TRIALS) IN KG x CM OF THE TRAINED KNEE EXTENSORS COMPARED TO THE CONTROLS[1]

Sex and Side	Time of Test	Group 1 5 females 5 males 1 isom. contr/day	Group 11 4 females 6 males 10 isom. contr/day	Controls 7 females 6 males no training
Females				
right side	before training.	1,328±141	1,128±81	1,319±129
	after 9 days	1,206±105	1,088±46	1,224±103
	after 18 days	1,210±106	1,078±76	1,229±105
	after 20 days	---	---	---
	after 27 days	1,228±101	1,210±91	1,246±126
	after 36 days	1,230±100	1,230±87	1,233±112
left side	before training	---	---	1,237±110
	after 20 days	---	---	1,224±115
Males				
right side	before training	1,964±277	1,993±131	2,135±129
	after 9 days	1,860±264	1,993± 96	1,882± 76
	after 18 days	1,898±204	1,945±114	1,770± 69
	after 20 days	---	---	---
	after 27 days	2,010±269	2,141±129	2,007±121
	after 36 days	2,026±230	2,215±129	1,982±119
left side	before training	---	---	2,225± 98
	after 20 days	---	---	1,935±150

When the female group is disregarded the analysis of the right elbow flexors is not the same. In Group 1, for example, (1 isometric contraction a day) the male subjects showed a

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[1] From Petersen, "Muscle Training by Static, Concentric and Eccentric Contractions", *Acta physiol. scand.* vol. 48 (1960), p. 411.

progressive increase in strength from 790 ± 48 to 810 ± 110 to 818 ± 56 to 826 ± 68 to the final test of 837 ± 78, all measures in kg x cm of the trained elbow flexors. In Group 11 (10 isometric contractions a day) the evidence with respect to the male population is more conclusive. The group started at one initial mean of 829 ± 33, went to 897 ± 35 after nine days then to 860 ± 43 after eighteen days, 880 ± 57 over twenty-seven days and 962 ± 49 kg x cm after thirty-six days. These findings have not been treated statistically but they represent an increase in strength, in five weeks, of approximately five percent in the group performing one isometric contraction a day and thirteen percent in the group performing ten isometric contractions a day.

When the knee extensors are considered (see Table 1X), the males increased from 1,964 ± 277 to 2,026 ± 230 kg x cm for the group performing one isometric contraction daily; and from 1,993 ± 131 to 2,215 ± 125 kg x cm for the group performing ten isometric contractions daily.

Petersen then comments (29:410-411):

> "In Group 11 who trained with ten isometric contractions per day no significant increase was found in the two muscle groups trained. Expressing the increase as percent change enables a statistical treatment of both the trained muscle groups as a single group. The increase in the female group was five percent (not significant) and in the male thirteen percent with a significance of 0.01."

These comments are ignored in the main conclusions, which are that "... ten daily maximum isometric contractions had a tendency to increase the isometric strength of the muscles..." It could also have been concluded, based on the evidence presented in the study, that ten daily maximum contractions caused statistically significant increases in the isometric strength of the muscles of the male subjects used in his study.

Age is another factor, which has likewise shown to be a variable (3,6,13). The present study used high school boys with an age range of sixteen to eighteen years, whereas the Petersen study used the age range of between eighteen to thirty-one. This could occasion differences.

Another refinement in procedure in the present study was to use the average rather than the best score as the strength score. This procedure was recommended by Whitley and Smith (41), and thus the score used for statistical analysis, in the present study, more nearly approximated the individual's true performance. Petersen, on the other hand, used the maximum of five trials as the strength score.

In summary, then, this study tends to support the general findings of Hettinger and Müller and yet the design did not parallel their research. The explanation of the discrepancy of Hettinger and Müller's findings with those of Petersen were debated on different grounds.

As Hettinger said (13:195)

> ...His conclusion is not the same as ours, but he expected a training effect in a dimension which we have very seldom found in our ten years of training experiments. He trained one group of subjects with one maximum muscle contraction a day against resistance, and trained a second group by another method. He then took the average strength increase in both groups and found better trainability in one group than in the other. The result is not correct. It may be that one group had more subjects with good trainability than the other groups. It has already been shown how individual trainability changes in high degree. In experiments like these, as has been demonstrated, only a comparison between the same muscle groups on the left and the right side of the same individual, trained by different methods, can give a justified conclusion.

It might be interesting in future experimentation to examine the results and design the experiments to answer both research groups; to train on one apparatus and test on another to minimize the learning factor, and also to use contralateral limb as the control.

There has been some conjecture as to the effects of isometric exercises of a normal nature on injuries and pain. Start (36), and Rasch et al.(33) have published contradictory findings. The age group may have been a factor in the present experiment, but there were no injuries in the study which necessitated cessation of daily training and very few subjects reported occurrences of even the slightest discomfort.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate the effect of varying the number of maximal isometric contractions on the development of strength in the knee extensors.

One hundred grade ten boys from Bonnie Doon Composite High School, in the city of Edmonton, served as the subjects. They were ranked in order, highest to lowest, on the basis of their initial strength scores. They were randomly placed in one of the four groups. Each group contained twenty-five subjects.

Three of the groups took part in the isometric training program, with the fourth acting as the control group.

Group 1 performed one six second maximal isometric contraction per day, five days a week. Group 11 performed ten six second maximal contractions daily with a rest period of three seconds between each contraction, five days per week. Group 111 performed twenty, six second maximal contractions daily with a rest period of three seconds between contractions, five days per week.

The initial, mid (two and a half weeks) and final test (five weeks) for strength were measured by use of the Clarke Testing Table, and the Cable-Tensiometer. The training program was carried out on a modified quadriceps table.

On the basis of the statistical analysis the following conclusions appear to be justified:

1. One daily maximal six second isometric contraction increased significantly the isometric strength of the knee extensors.

2. Ten daily maximal six second isometric contractions increased significantly the isometric strength of the knee extensors.

3. Twenty daily maximal six second isometric contractions increased significantly the isometric strength of the knee extensors.

4. There were no statistically significant differences between any one of the three experimental groups.

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APPENDIX A

STATISTICAL TREATMENT

STATISTICAL TREATMENT

<u>Reliability of the strength Test.</u> The reliability coefficient, was obtained by use of Pearson's Product - Moment correlation coefficient and was computed from test-retest results.

The formula used was:

$$r = \frac{N\Sigma XY - \Sigma X - \Sigma Y}{\sqrt{\left[N\Sigma X^2 - (\Sigma X)^2\right]\left[N\Sigma Y^2 - (\Sigma Y)^2\right]}}$$

where X = test score
Y = retest score

$$r = \frac{36{,}926{,}250.0 - 35{,}825{,}272.0}{\sqrt{\left[39{,}780{,}300 - 38{,}390{,}416\right]\left[34{,}618{,}020 - 33{,}431{,}524\right]}}$$

$$r = \frac{1{,}100{,}978}{1{,}284{,}205}$$

$$r = .857$$

<u>Analysis of Variance.</u> The analysis of variance (direct calculation of a three-factor interaction) (7:207) was used to evaluate the significance of the different scores (initial-mid-final).

<u>Total Sums of Squares.</u>

	Initial	Mid	Final	
Control	5,054	5,297	5,342	15,693
1 Contraction	5,075	5,981	6,582	17,638
10 Contractions	5,072	5,932	6,687	17,691
20 Contractions	5,090	6,114	7,026	18,230
Total	20,291	23,324	25,637	69,252

Correction Factor (C.F.) $= \frac{(69,252)^2}{300}$

$- 15,986,131$

Sum of Squares $= \left(\frac{290}{1}\right)^2 + \left(\frac{270}{1}\right)^2 + \ . \ . \ . + \left(\frac{193}{1}\right)^2 + \left(\frac{220}{1}\right)^2$
$- \text{C.F.}$
$= 845,637$

Sum of Groups $= \left(\frac{15,693}{75}\right)^2 + \ . \ . \ . + \left(\frac{18,230}{75}\right)^2 - \text{C.F.}$
$= 49,518$

Sum of Trials $= \left(\frac{20,291}{100}\right)^2 + \ . \ . \ . + \left(\frac{25,637}{100}\right)^2 - \text{C.F.}$

$= 143,763$

<u>Sum of Squares For Blocks</u>

No.	Control	1 Contraction	10 Contractions	20 Contractions
1	835	987	899	951
2	770	883	749	957
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
25	600	439	429	505

Sum of Squares for Blocks $= \frac{(835+987+899+951)^2}{12}$
$+ \frac{(770+883+749+957)^2}{12}$
$+ \frac{(600+439+429+505)^2}{12} - \text{C.F.}$
$= 398,251$

Blocks By Groups

No.	Control	1 Contraction	10 Contractions	20 Contractions
1	835	987	899	951
2	770	883	749	957
3	812	780	963	868
4	736	716	769	912
5	752	856	804	912
6	696	784	752	770
7	689	834	785	756
8	682	738	814	741
9	687	821	771	726
10	648	725	754	770
11	656	746	868	796
12	649	683	704	894
13	688	747	556	818
14	591	844	696	668
15	587	679	603	723
16	515	678	671	703
17	490	626	776	707
18	492	677	639	578
19	518	572	600	653
20	585	603	648	543
21	568	628	566	564
22	452	588	596	597
23	563	554	741	585
24	432	553	588	483
25	600	439	429	505

$$\text{Between Cells} = \frac{(835)^2}{3} + \frac{(770)^2}{3} + \ldots + \frac{(483)^2}{3} + \frac{(505)^2}{3} - \text{C.F.}$$

$$= 16{,}536{,}932 - 15{,}986{,}131$$

$$= 550{,}801$$

Blocks X Groups S.S. = Between Cell S.S. - (Blocks S.S.+

Groups S.S.).

$$= 550{,}801 - 447{,}769$$

$$= 103{,}032$$

Groups By Trials

$$\text{Between Cells} = \left(\frac{5{,}054}{25}\right)^2 + \left(\frac{5297}{25}\right)^2 + \;.\;\;.\;\;. + \left(\frac{6{,}114}{25}\right)^2 + \left(\frac{7026}{25}\right)^2 - \text{C.F.}$$

$$= 16{,}210{,}894 - 15{,}986{,}131$$

$$= 224{,}763$$

$$\text{Between Groups} = \left(\frac{15{,}693}{75}\right)^2 + \;.\;\;.\;\;. + \left(\frac{18{,}230}{75}\right)^2 - \text{C.F.}$$

$$= 16{,}035{,}649 - 15{,}986{,}131$$

$$= 49{,}518$$

$$\text{Between Trials} = \left(\frac{20{,}291}{100}\right)^2 + \;.\;\;.\;\;. + \left(\frac{25{,}637}{100}\right)^2 - \text{C.F.}$$

$$= 16{,}129{,}894 - 15{,}986{,}131$$

$$= 143{,}763$$

Groups By Trials S.S. = Between Cells - (Sum of Groups + Sum of Trials)

$$= 224{,}763 - 193{,}281$$

$$= 31{,}482$$

Blocks By Trials

No.	Trial 1	Trial 2	Trial 3
1	1180	1192	1300
2	1090	1113	1156
3	1034	1154	1235
4	1004	995	1134
5	984	1133	1207
6	961	961	1080
7	929	1026	1109
8	920	948	1107
9	906	1028	1071
10	883	967	1047
11	836	1099	1131
12	804	1003	1123
13	800	897	1112
14	788	964	994
15	766	790	1036
16	750	839	978
17	717	904	978
18	694	825	867
19	671	842	830
20	649	844	936
21	637	732	857
22	626	753	854
23	597	872	974
24	557	735	764
25	508	708	757

$$\text{Between Cells} = \left(\frac{1180}{4}\right)^2 + \left(\frac{1192}{4}\right)^2 + \ . \ . \ . + \left(\frac{708}{4}\right)^2 + \left(\frac{757}{4}\right)^2 - \text{C.F.}$$

$$= 16{,}558{,}058 - 15{,}986{,}131$$

$$= 571{,}927$$

Blocks By Trials = Between Cells - (Block Sum+Trial Sum)

$$= 571{,}927 - 542{,}014$$

$$= 29{,}913$$

Blocks By Trials By Groups

Control

Between Cells $= \frac{(290)^2}{1} + \frac{(285)^2}{1} + \ldots + \frac{(240)^2}{1} + \frac{(230)^2}{1}$

$- \frac{(15,693)^2}{75}$

$= 3,405,965 - 3,283,603$

$= 122,362$

Rows $= \frac{(835)^2}{3} + \frac{(770)^2}{3} + \ldots + \frac{(432)^2}{3} + \frac{(600)^2}{3} - \frac{(15,693)^2}{75}$

$= 3,379,998 - 3,283,603$

$= 96,395$

Columns $= \frac{(5054)^2}{25} + \ldots + \frac{(5342)^2}{25} - \frac{(15,693)^2}{75}$

$= 3,285,524 - 3,283,603$

$= 1,921$

Gp.$_1$ (Blocks Trials) = Between Cells - (Rows+Columns)

$= 122,362 - 98,316$

$= 24,046$

One Contraction

Between Cells $= \frac{(300)^2}{1} + \frac{(307)^2}{1} + \ldots + \frac{(154)^2}{1} + \frac{(152)^2}{1}$

$- \frac{(17,638)^2}{75}$

$= 4,356,568 - 4,147,987$

$= 208,581$

$$\text{Rows} = \frac{(987)^2}{3} + \frac{(883)^2}{3} + \ldots + \frac{(553)^2}{3} + \frac{(439)^2}{3} - \frac{(17{,}638)^2}{75}$$

$$= 4{,}280{,}721 - 4{,}147{,}987$$

$$= 132{,}734$$

$$\text{Column} = \frac{(5075)^2}{25} + \ldots + \frac{(6582)^2}{25} - \frac{(17{,}638)^2}{75}$$

$$= 46{,}041$$

$$\text{Gp.}_2 \text{ (Blocks Trials)} = \text{Between Cells} - (\text{Rows}+\text{Column})$$

$$= 208{,}581 - (132{,}734 + 46{,}041)$$

$$= 29{,}806$$

$$\begin{array}{l}\text{Ten Contractions} \\ \quad \text{Between Cells}\end{array} = \frac{(295)^2}{1} + \frac{(280)^2}{1} + \ldots + \frac{(154)^2}{1} + \frac{(155)^2}{1} - \frac{(17{,}691)^2}{75}$$

$$= 4{,}382{,}345 - 4{,}172{,}953$$

$$= 209{,}392$$

$$\text{Rows} = \frac{(899)^2}{3} + \frac{(749)^2}{3} + \ldots + \frac{(588)^2}{3} + \frac{(429)^2}{3} - \frac{(17{,}691)^2}{75}$$

$$= 4{,}291{,}937 - 4{,}172{,}953$$

$$= 118{,}984$$

$$\text{Column} = \frac{(5072)^2}{25} + \ldots + \frac{(6687)^2}{25} - \frac{(17{,}691)^2}{75}$$

$$= 4{,}225{,}191 - 4{,}172{,}953$$

$$= 52{,}238$$

Gp._3 (Blocks Trials) = Between Cells - (Rows+Column)

= 209,392 - (118,984+52,238)

= 209,392 - 171,222

= 38,170

Twenty Contractions

$$\text{Between Cells} = \left(\frac{295}{1}\right)^2 + \left(\frac{320}{1}\right)^2 + \ldots + \left(\frac{160}{1}\right)^2 + \left(\frac{220}{1}\right)^2 - \left(\frac{18,230}{75}\right)^2$$

= 4,686,890 - 4,431,105

= 255,785

$$\text{Rows} = \left(\frac{951}{3}\right)^2 + \left(\frac{957}{3}\right)^2 + \ldots + \left(\frac{483}{3}\right)^2 + \left(\frac{505}{3}\right)^2 - \left(\frac{18,230}{75}\right)^2$$

= 4,584,276 - 4,431,105

= 153,171

$$\text{Column} = \left(\frac{5090}{25}\right)^2 + \ldots + \left(\frac{7026}{25}\right)^2 - \left(\frac{18,230}{75}\right)^2$$

= 4,506,150 - 4,431,105

= 75,045

Gp._4 (Blocks·Trials) = Between Cells - (Rows+Column)

= 255,785 - (153,171+75,045)

= 255,785 - 228,216

= 27,569

Blocks By Trials By Groups $= \Sigma \text{Gp.}_1 + \Sigma \text{Gp.}_2 + \Sigma \text{Gp.}_3 + \Sigma \text{Gp.}_4$ - Blocks By Trials

= 119,591 - 29,913

= 89,678

Duncans New Multiple Range Test (Means Final Trials)

No.	Control	1 Contraction	10 Contractions	20 Contractions
1	260	380	324	336
2	256	306	244	350
3	280	248	357	350
4	252	237	265	380
5	300	295	280	332
6	220	295	275	290
7	233	306	300	270
8	252	256	324	275
9	220	306	285	260
10	212	265	280	290
11	208	260	350	313
12	233	260	260	370
13	248	320	216	328
14	197	337	216	244
15	190	306	240	300
16	163	260	275	280
17	155	223	340	260
18	145	270	252	200
19	155	212	233	230
20	208	220	252	256
21	204	233	216	204
22	150	223	216	265
23	226	212	306	230
24	145	200	226	193
25	230	152	155	220

Total Sum of Squares

$$\Sigma^2 - \frac{(\Sigma)^2}{100}$$

$$= 6,869,859 - \frac{657,255,769}{100}$$

$$= 6,869,859 - 6,572,558$$

$$= 297,301$$

Between Groups

$$= \left(\frac{5342}{25}\right)^2 + \ . \ . \ . + \left(\frac{7026}{25}\right)^2 - \left(\frac{25,637}{100}\right)^2$$

$$= 6,637,613 - 6,572,558$$

$$= 65,055$$

Within Groups

$= 297,301 - 65,055$

$= 232,246$

Standard Error of Mean

$$S_{\bar{x}} = \frac{s}{\sqrt{n}}$$

$$S_{\bar{x}} = \frac{\sqrt{2419}}{\sqrt{25}}$$

$$S_{\bar{x}} = \frac{49.5}{5}$$

$$= 9.9$$

Shortest Significant Ranges (R) (.01)

K	2(213.7)	3(263.3)	4(267.5)
Significant Studentized Ranges	3.738	3.89	3.998
$R = \left(S_{\bar{x}} \text{ X Significant Studentized Ranges} \right)$	37.0	38.5	39.6

Mean	213.7	263.3	267.5	281.0	Shortest Significant Ranges
213.7		49.6	54.2	67.3	R= 37.0
263.3			4.2	17.7	R= 38.5
267.5				13.5	R= 39.6

APPENDIX B

RAW SCORES

RAW STRENGTH SCORES

INITIAL-TRIAL

RANKED HIGH TO LOW

No.	Trials			Average	Score	No.	Trials			Average	Score
	1	2	3				1	2	3		
1	77	75	73	75	300	51	55	57	41	51	200
2	76	74	71	74	295	52	53	49	50	51	200
3	76	68	77	74	295	53	52	48	49	50	197
4	75	73	72	73	290	54	52	49	48	50	197
5	68	74	68	70	275	55	51	54	45	50	197
6	71	78	60	70	275	56	53	49	48	50	197
7	74	68	65	69	270	57	52	49	47	49	193
8	74	68	66	69	270	58	56	52	40	49	193
9	71	70	67	69	270	59	48	50	46	48	190
10	66	65	66	66	256	60	49	49	47	48	190
11	72	62	64	66	256	61	51	48	44	48	190
12	70	66	60	65	252	62	47	49	49	48	190
13	70	64	62	65	252	63	48	46	56	47	185
14	72	60	64	65	252	64	48	46	47	47	185
15	65	67	62	65	252	65	51	45	42	46	180
16	60	66	66	64	248	66	48	42	47	46	180
17	66	64	62	64	248	67	49	45	45	46	180
18	66	63	62	64	248	68	49	44	42	45	177
19	63	63	64	63	244	69	48	48	39	45	177
20	67	61	61	63	244	70	40	48	48	45	177
21	65	63	60	63	244	71	49	41	40	43	170
22	68	62	56	62	240	72	44	44	42	43	170
23	62	61	62	62	240	73	47	40	42	43	170
24	64	61	61	61	237	74	47	39	41	42	167
25	59	60	60	60	233	75	46	41	40	42	167
26	63	59	59	60	233	76	46	39	40	42	167
27	62	60	57	60	233	77	42	42	39	41	163
28	66	58	54	59	230	78	40	43	39	41	163
29	66	60	52	59	230	79	43	38	41	41	163
30	61	57	59	59	230	80	36	44	40	40	160
31	62	60	56	59	230	81	47	35	38	40	160
32	64	59	55	59	230	82	40	40	40	40	160
33	60	60	57	59	230	83	41	42	38	40	160
34	58	60	59	59	230	84	43	38	37	39	157
35	51	59	62	57	223	85	43	40	34	39	157
36	62	54	55	57	223	86	34	41	42	39	157
37	60	57	53	57	223	87	41	38	39	39	157
38	60	58	51	56	220	88	40	36	38	38	155
39	61	55	53	56	220	89	42	34	38	38	155
40	60	58	49	56	220	90	31	35	41	36	150
41	56	57	52	55	216	91	40	33	33	35	147
42	50	56	53	53	208	92	30	36	36	34	145
43	62	52	44	53	208	93	34	34	32	33	142
44	61	49	47	52	204	94	38	32	30	33	142
45	56	50	50	52	204	95	34	31	31	32	140
46	52	52	51	52	204	96	29	30	32	30	133
47	52	50	50	51	200	97	32	26	31	30	133
48	52	54	46	51	200	98	30	24	34	29	130
49	58	51	44	51	200	99	34	24	24	27	125
50	58	48	46	51	200	100	26	25	24	25	120

INTIAL STRENGTH SCORES

RANKED HIGH TO LOW

No.	Pounds	No.	Pounds	No.	Pounds	No.	Pounds
1	300	26	233	51	200	76	167
2	295	27	233	52	200	77	163
3	295	28	230	53	197	78	163
4	290	29	230	54	197	79	163
5	275	30	230	55	197	80	160
6	275	31	230	56	197	81	160
7	270	32	230	57	193	82	160
8	270	33	230	58	193	83	160
9	270	34	230	59	190	84	157
10	256	35	223	60	190	85	157
11	256	36	223	61	190	86	157
12	252	37	223	62	190	87	157
13	252	38	220	63	185	88	155
14	252	39	220	64	185	89	155
15	252	40	220	65	180	90	150
16	248	41	216	66	180	91	147
17	248	42	208	67	180	92	145
18	248	43	208	68	177	93	142
19	244	44	204	69	177	94	142
20	244	45	204	70	177	95	140
21	244	46	200	71	170	96	133
22	240	47	200	72	170	97	133
23	240	48	200	73	170	98	130
24	237	49	200	74	167	99	125
25	233	50	200	75	167	100	120

GROUPS BASED ON INTIAL

RANKED SCORES

	Group 1 1 Contraction	Group 2 10 Contractions	Group 3 20 Contractions	Group 4 Control
No. 1	300	295	295	290
2	270	275	275	270
3	256	256	270	252
4	252	252	252	248
5	248	244	248	244
6	237	240	240	244
7	233	233	230	233
8	230	230	230	230
9	223	230	230	223
10	223	220	220	220
11	216	204	208	208
12	200	200	204	200
13	200	200	200	200
14	197	197	197	197
15	193	190	190	193
16	185	190	190	185
17	180	180	177	180
18	177	177	170	170
19	167	167	167	170
20	163	163	160	163
21	157	160	160	160
22	157	157	157	155
23	145	150	155	147
24	133	142	140	142
25	133	120	125	130

RELIABILITIES - REPEATS

THIRTY SCORES

No.	Group	Trials			Average	Score
		1	2	3		
18	2	53	49	50	51	200
21	2	37	39	39	38	155
11	1	52	51	50	51	200
17	2	67	55	55	59	230
8	3	62	60	54	59	230
16	4	47	49	48	48	190
19	3	44	42	45	44	173
22	2	56	56	54	55	216
23	1	44	37	40	40	160
22	4	44	34	41	40	160
21	3	49	45	44	46	180
23	3	43	36	36	38	155
18	3	39	41	40	40	160
8	4	66	58	64	63	244
17	4	44	46	47	46	180
17	1	48	48	46	47	185
13	3	57	54	52	54	212
24	3	41	32	23	32	140
16	3	57	51	51	53	208
4	1	60	59	60	60	233
25	3	44	40	39	42	167
4	4	60	60	62	61	237
7	2	74	70	70	71	280
16	2	62	55	57	58	226
15	4	54	48	41	48	190
3	2	64	70	82	73	290
13	1	62	61	56	60	233
10	2	70	66	66	67	260
6	3	60	61	61	61	237
5	1	70	68	66	68	265

GROUP 1 ONE CONTRACTION

MID - FINAL TESTING

No.	Trials			Average	Score	No.	Trials			Average	Score
	1	2	3				1	2	3		
1	78	73	75	76	307	1	94	90	88	91	380
2	79	73	76	76	307	2	80	74	72	75	306
3	72	68	69	70	276	3	72	56	61	64	248
4	61	55	57	58	227	4	64	61	59	61	237
5	76	78	77	77	313	5	74	75	73	74	295
6	68	62	66	65	252	6	77	74	72	74	295
7	76	72	73	74	295	7	78	77	74	76	306
8	70	60	65	65	252	8	68	65	66	66	256
9	75	72	74	74	292	9	76	79	74	76	306
10	66	55	58	61	237	10	67	69	67	68	265
11	70	68	70	69	270	11	64	70	67	67	260
12	56	57	58	57	223	12	71	66	65	67	260
13	60	55	59	58	227	13	80	81	78	80	320
14	80	73	75	76	307	14	84	82	81	82	337
15	44	48	47	46	180	15	69	71	66	76	306
16	63	56	60	60	233	16	74	69	68	67	260
17	58	56	56	57	223	17	61	56	53	57	223
18	58	59	59	59	230	18	64	63	60	69	270
19	48	50	48	49	193	19	56	54	52	54	212
20	62	49	60	56	220	20	59	55	55	56	220
21	31	33	30	31	138	21	63	60	58	60	233
22	58	48	55	53	208	22	55	56	50	57	223
23	52	48	49	50	197	23	59	53	49	54	212
24	59	53	54	56	220	24	53	50	49	51	200
25	40	35	36	38	154	25	37	35	38	37	152

GROUP 2 TEN CONTRACTIONS

MID - FINAL TESTING

Mid						Final					
No.	Trials			Average	Score	No.	Trials			Average	Score
	1	2	3				1	2	3		
1	70	71	71	71	280	1	79	80	78	79	324
2	68	52	60	60	230	2	64	62	63	63	244
3	84	85	85	85	350	3	86	87	85	86	357
4	64	66	64	65	252	4	69	68	66	68	265
5	72	70	71	71	280	5	71	73	70	71	280
6	62	60	62	61	237	6	75	69	67	70	275
7	68	62	63	65	252	7	74	77	75	75	300
8	74	59	63	67	260	8	81	79	77	79	324
9	66	66	66	66	256	9	75	71	69	72	285
10	69	62	63	65	254	10	76	70	68	71	280
11	75	78	77	77	314	11	92	84	80	85	350
12	66	59	63	63	244	12	76	60	66	67	260
13	34	30	31	32	140	13	59	54	51	55	216
14	61	58	60	60	233	14	58	53	53	55	216
15	40	47	43	44	173	15	64	62	61	62	240
16	56	50	53	53	208	16	73	70	67	70	275
17	72	60	65	66	256	17	84	86	80	83	340
18	56	50	53	53	208	18	66	64	65	65	252
19	54	47	52	51	200	19	61	60	58	60	233
20	60	60	60	60	233	20	67	65	63	65	252
21	49	47	48	48	190	21	54	56	56	55	216
22	58	56	57	57	223	22	60	51	54	55	216
23	71	73	72	72	285	23	76	77	74	76	306
24	55	56	56	56	220	24	61	58	55	58	226
25	40	34	36	37	154	25	38	40	37	38	155

GROUP 3 TWENTY CONTRACTIONS

MID - FINAL TESTING

No.	Mid Trials			Average	Score	No.	Final Trials			Average	Score
	1	2	3				1	2	3		
1	78	78	77	78	320	1	84	82	81	82	336
2	78	83	80	81	332	2	88	85	82	85	350
3	63	65	65	64	248	3	90	86	80	85	350
4	74	68	70	71	280	4	93	91	88	91	380
5	84	78	82	81	332	5	81	83	80	81	332
6	66	58	63	62	240	6	74	73	72	73	290
7	64	68	65	66	256	7	71	69	66	69	270
8	61	60	61	61	236	8	64	71	74	70	275
9	64	58	62	61	236	9	70	65	65	67	260
10	71	64	68	67	260	10	80	71	67	73	290
11	70	70	70	70	275	11	82	76	74	77	313
12	80	75	78	78	320	12	90	91	88	90	370
13	75	71	72	73	290	13	84	80	77	80	328
14	60	56	58	58	227	14	66	63	60	63	244
15	52	68	55	60	233	15	80	72	74	75	300
16	60	60	61	60	233	16	71	66	65	71	280
17	68	69	69	69	270	17	70	65	67	67	260
18	55	51	52	53	208	18	54	50	50	51	200
19	68	64	65	66	256	19	61	59	57	59	230
20	48	42	44	45	177	20	71	63	64	66	256
21	55	46	52	51	200	21	55	52	50	52	204
22	44	43	45	44	175	22	74	64	67	68	265
23	52	50	51	51	200	23	59	60	58	59	230
24	41	30	37	36	150	24	51	47	48	49	193
25	46	34	40	40	160	25	60	53	54	56	220

GROUP 4 CONTROL

MID - FINAL TESTING

Mid						Final					
No.	Trials			Average	Score	No,	Trials			Average	Score
	1	2	3				1	2	3		
1	74	71	72	72	285	1	73	65	63	67	260
2	65	61	62	63	244	2	68	67	63	66	256
3	72	70	71	71	280	3	75	71	67	71	280
4	66	56	61	61	236	4	67	66	63	65	252
5	55	50	52	53	208	5	79	76	72	75	300
6	61	60	60	60	232	6	58	57	53	56	220
7	57	59	56	57	223	7	60	62	58	60	233
8	56	45	52	51	200	8	72	65	59	65	252
9	66	61	62	63	244	9	59	53	55	56	220
10	55	55	54	55	216	10	55	55	53	54	212
11	64	60	62	62	240	11	54	51	54	53	208
12	58	53	54	55	216	12	62	62	57	60	233
13	60	63	62	62	240	13	72	58	63	64	248
14	53	47	50	50	197	14	48	55	47	50	197
15	56	47	53	52	204	15	51	48	45	48	190
16	42	42	41	42	167	16	42	42	40	41	163
17	39	38	38	38	155	17	39	38	36	38	155
18	48	42	43	45	177	18	38	31	33	34	145
19	54	42	47	48	193	19	41	38	36	38	155
20	55	56	52	54	214	20	56	51	52	53	208
21	53	50	51	52	204	21	56	51	48	52	204
22	36	34	35	35	147	22	38	36	33	36	150
23	50	46	47	48	190	23	63	54	57	58	226
24	33	35	34	34	145	24	36	33	32	34	145
25	65	60	61	62	240	25	59	62	56	54	230

COMBINED SCORES

ALL GROUPS

	CONTROL			1 CONTRACTION			10 CONTRACTIONS			20 CONTRACTIONS		
No.	Init	Mid	Fin	Init	Mid	Fin	Init	Mid	Fin	Init	Mid	Fin
1	290	285	260	300	307	380	295	280	324	295	320	336
2	270	244	256	270	307	306	275	230	244	275	332	350
3	252	280	280	256	276	248	256	350	357	270	248	350
4	248	236	252	252	227	237	252	252	265	252	280	380
5	244	208	300	248	313	295	244	280	280	248	332	332
6	244	232	220	237	252	295	240	237	275	240	240	290
7	233	223	233	233	295	306	233	252	300	230	256	270
8	230	200	252	230	252	256	230	260	324	230	236	275
9	223	244	220	223	292	306	230	256	285	230	236	260
10	220	216	212	223	237	265	220	254	280	220	260	290
11	208	240	208	216	270	260	204	314	350	208	275	313
12	200	216	233	200	223	260	200	244	260	204	320	370
13	200	240	248	200	227	320	200	140	216	200	290	328
14	197	197	197	197	307	337	197	233	216	197	227	244
15	193	204	190	193	180	306	190	173	240	190	233	300
16	185	167	163	185	233	260	190	206	275	190	233	280
17	180	155	155	180	223	223	180	256	340	177	270	260
18	170	177	145	177	230	270	177	210	252	170	208	200
19	170	193	155	167	193	212	167	200	233	167	256	230
20	163	214	208	163	220	220	163	233	252	160	177	256
21	160	204	204	157	138	233	160	190	216	160	200	204
22	155	147	150	157	208	223	157	223	216	157	175	265
23	147	190	226	145	197	212	150	285	306	155	200	230
24	142	145	145	133	220	200	142	220	226	140	150	193
25	130	240	230	133	154	152	120	154	155	125	160	220

WEIGHTS AND HEIGHTS

	Pre								Post							
Group	1		2		3		4		1		2		3		4	
No.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.	Wt.	Ht.
1	178	69.5	132	66.5	139	71.0	152	67.8	175	69.5	131	66.5	139	70.8	154	69.0
2	180	68.5	130	67.0	153	72.0	138	64.0	182	68.5	128	67.0	151	72.0	138	64.0
3	137	69.0	139	68.5	145	68.3	144	68.3	139	69.0	141	68.5	144	68.5	144	64.5
4	140	71.1	155	69.0	160	72.5	137	67.0	143	71.2	152	68.0	163	73.3	140	66.8
5	144	68.5	141	66.7	159	70.0	133	67.0	140	68.5	140	66.7	159	69.3	132	67.5
6	182	69.0	140	67.5	180	71.3	142	69.3	184	69.0	138	67.7	181	71.5	140	69.8
7	152	67.0	138	68.0	164	71.0	134	71.8	152	67.0	136	68.0	158	71.0	134	72.0
8	165	66.5	165	72.0	170	71.0	140	67.0	163	66.5	163	71.0	171	71.0	137	66.5
9	160	73.5	135	69.0	142	70.0	133	68.5	163	73.5	136	68.5	143	70.5	131	69.5
10	134	69.5	137	69.0	134	69.0	121	65.8	133	69.5	135	69.0	136	69.0	121	65.5
11	136	66.3	120	67.5	129	67.0	136	68.8	134	66.3	121	67.5	131	67.0	137	68.5
12	128	67.0	125	66.3	160	69.5	137	69.8	129	67.0	127	66.3	159	69.5	138	70.8
13	178	72.0	115	65.5	127	66.5	127	63.3	179	71.5	117	65.5	128	66.8	126	64.0
14	130	69.5	135	67.0	121	66.5	140	69.5	133	69.5	132	67.0	123	67.0	141	69.5
15	150	69.0	125	68.0	123	67.0	137	67.0	156	69.0	120	67.5	125	66.5	137	67.3
16	162	68.0	120	67.3	129	68.5	112	66.5	159	68.0	125	67.0	130	68.3	111	66.3
17	130	67.0	153	67.5	146	69.0	128	68.0	121	67.0	153	67.5	146	68.5	127	67.8
18	123	62.5	141	69.0	119	65.0	118	65.5	125	62.5	140	68.0	120	64.8	133	67.0
19	120	65.0	150	68.0	143	65.7	110	63.0	118	65.0	152	68.5	141	65.8	108	63.5
20	130	64.0	132	67.0	136	65.8	126	67.5	132	64.0	133	66.0	137	66.0	126	67.5
21	138	66.3	119	69.0	119	63.0	144	68.0	138	63.0	120	68.8	118	62.0	144	68.0
22	115	62.3	117	63.0	132	66.0	96	62.0	118	62.5	119	63.0	129	66.0	96	61.5
23	110	65.0	148	70.7	129	66.7	125	64.0	110	65.0	144	70.8	127	66.0	113	64.5
24	145	67.0	145	70.7	118	66.0	123	64.5	143	67.0	156	70.8	120	65.5	124	64.5
25	95	60.5	91	68.3	154	68.5	125	65.0	93	60.5	90	68.5	159	69.0	125	65.0

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